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Analysis and Decomposition of the Energy Intensity of California Industries

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Abstract

In 2008, the gross domestic product (GDP) of California industry was larger than GDP of industry in any other U.S. states. This study analyses the energy use of and output from seventeen industry subsectors in California and performs decomposition analysis to assess the influence of different factors on California industry energy use. The logarithmic mean Divisia index method is used for the decomposition analysis. The decomposition analysis results show that the observed reduction of energy use in California industry since 2000 is the result of two main factors: the intensity effect and the structural effect. The intensity effect has started pushing final energy use downward in 2000 and has since amplified. The second large effect is the structural effect. The significant decrease of the energy-intensive "Oil and Gas Extraction" subsector's share of total industry value added, from 15% in 1997 to 5% in 2008, and the increase of the non-energy intensive "Electric and electronic equipment manufacturing" sector's share of value added, from 7% in 1997 to 30% in 2008, both contributed to a decrease in the energy intensity in the industry sector.

Keywords: Decomposition analysis; Energy intensity indicator; California industry

1. Introduction

In 2008, the gross domestic product (GDP) of California industry was $1,847 billion which was larger than GDP of industry in any other U.S. states in that year (USEIA, 2010). California industry comprises many sectors, some of which are large and energy-intensive, such as "Oil refineries," "Oil and gas extraction," and "Nonmetallic minerals" (Coito et al. 2005a). During the past two decades, the structure of California's industry has been changing with the elimination of heavy, energy-consuming industries and the rise of less-energy-intensive industries such as "Electric and electronic equipment manufacturing." No research to date has looked at the effect on energy demand of this change in the

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relative share of industry subsectors. This paper fills this gap by quantifying the effects that structural and intensity changes have had on California industry energy demand during the past 10 years.

Energy-to-GDP ratios have been widely used internationally to measure the energy efficiency performance of national economies, until a body of research exposed the limits of using this indicator (Schipper et al. 1992; Patterson 1993; Ang and Lee 1994; and IEA 2004). Energy analysts demonstrated that factors other than energy intensity were affecting changes in energy use; mainly the level of aggregate activity (activity effect), and the composition of various activities (structure effect). Techniques of factorization or decomposition analysis were developed to isolate the energy intensity effect in order to give a better estimate of energy efficiency improvements. Ang (2004) provides a complete review of the different aspects and evolution of these techniques. Ultimately, the more the effects affecting energy use are isolated; the better is the estimate of energy intensity effect. However, the drawback is the limit of available data that allow factorizing additional component of the decomposition analyses.

In 1997, Energy Policy devoted a complete issue on the subject (vol 25, issue7-9). For Schipper et al. (1997; 2001), energy indicators describe the link between energy consumption and human activity. Several authors refer to an energy indicators pyramid to help conceptualize the level of energy efficiency considered (Worrell et al., 1997; Phylipsen et al., 1998; Schipper et al., 1997; APERC, 2001). With each level of desegregation of indicators constructed, it is possible to isolate additional effects that influence our energy consumption.

Recently, a number of countries have focused on developing indices that are based on energy efficiency effects calculated at a disaggregate level, but which summarize results at more aggregate levels. The purpose of these indices is to provide a quick assessment tool to policy makers based on meaningful analysis. However, summing up energy intensities to get sector or national aggregates is often difficult. The problem stems from the fact that energy efficiency indicators are expressed in different units. Farla and Blok (2000) provide a method for aggregating physical indicators. However, this method has several challenges related to data requirement. Reviews of aggregation methods are well documented (Nanduri et al., 2002; Jollands et al., 2003; Ang, 2006).

In this study, the logarithmic mean Divisia index method is used for the decomposition analysis (Ang, 2005) which is discussed in more detail in section 2. The logarithmic mean Divisia index method has been increasingly used by analysts that have conducted decomposition analysis in the industry sector (Bhattacharyya and Ussanarassamee 2005; Reddy and Ray 2010; Salta, et al. 2009)

This study is part of a larger study, the "California Energy Balance Update and Decomposition Analysis for the Industry and Building Sectors," performed at Lawrence Berkeley National Laboratory for the California Energy Commission. More details about the California Energy Balance (CALEB) data, methodology, and results can be obtained from de la Rue du Can et al. (2011).

2. Methodology

Table 1 lists the industry sectors and subsectors included in this study. The research team collected energy use and production data as well as other information on 15 subsectors of the manufacturing sector, and two subsectors of the energy sector ("Oil refineries" and "Oil and gas extraction"). The term Industry used herein refers to "Manufacturing industries" plus "Oil refineries" and "Oil and gas extraction industries".

Table 1: List of Industry Subsectors Included in this Study

No.	Industry
	Manufacturing sector
1	Food product manufacturing
2	Textile and textile product mills
3	Apparel manufacturing
4	Wood product manufacturing
5	Furniture and related product manufacturing
6	Pulp and Paper manufacturing and Printing and Publishing
7	Chemical manufacturing
8	Plastics and rubber products manufacturing
9	Nonmetallic mineral product manufacturing
10	Primary metal manufacturing
11	Fabricated metal product manufacturing
12	Machinery manufacturing
13	Electric and Electronic Equipment manufacturing
14	Transportation equipment manufacturing
15	Miscellaneous manufacturing
	Energy sector
16	**Oil refineries**
17	**Oil and Gas Extraction**

2.1. Energy intensity calculation

The energy use data for this analysis came from California Energy Balance (de la Rue du Can et al., 2011), and the value added data came from the U.S. Department of Commerce Bureau of Economic Analysis (BEA/UDC, 2010). Using the energy use and output of each subsector, the authors calculated the subsector's energy intensity from the following equation:

$$\text{Energy Intensity (kWh or gigajoule / unit of output)} = \text{Energy consumption (kWh or gigajoule)} / \text{Production (unit of output)} \quad (1)$$

This study calculates energy intensity based on the economic output of each of the 17 industry subsectors. For three industrial categories/subsectors – "Cement" (the major energy consumer within the "Nonmetallic minerals" subsector), "Oil refineries," and "Oil and gas extraction" – energy intensity is also calculated based on physical output.

2.2. Decomposition analysis method

Decomposition analysis separates the effects of key components on energy end-use trends over time. Three main components that are usually considered in decomposition analysis are: 1) aggregate activity, 2) sectoral structure, and 3) energy intensity. The IEA defines these three components as (Unander et al., 2004):

1. *Aggregate activity*: Depending on the economic sector, this component is measured in different ways. For industry, it is measured as value added or physical output of the industry.
2. *Sectoral* structure: This component represents the mix of activities within a sector and further divides activity into subsectors.
3. *Energy intensity*: This component refers to energy use per unit of activity.

Different studies have used different mathematical techniques for decomposition analysis. Liu and Ang (2003) explain eight different methods for decomposing the aggregate energy intensity of industry into the impacts associated with aggregate activity, sectoral structure, and energy intensity. They argue that the choice of method can be influenced by limitations such as the data set (e.g., whether or not there are negative values) and the number of factors in the decomposition.

Ang et al. (2010) propose the LMDI method, which is recognized as superior in comparative studies such as Liu and Ang (2003). One of the LMDI method's main advantages (compared to other widely used methods such as the Laspeyres method) is that LMDI leaves no residual term, which in other methods can be large and affect the results and their interpretation. Two types of decomposition can be performed with LMDI: additive and multiplicative (Ang, 2005). The additive LMDI approach is easier to use and interpret, and its graphical results show effects in a clearer way than is the case for multiplicative analysis. The LMDI method can also be used for both changing and non-changing analysis. Changing analysis is based on yearly evaluations, and non-changing analysis is based on evaluation for a base-year period and an end-year period. For this study, the authors used additive LMDI decomposition analysis with changing analysis.

Ang (2005) provides practical guidelines for using the LMDI method. The formulas used in the additive LMDI method for decomposing energy use into activity, structural, and energy intensity effects are shown below (Ang, 2005):

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{act} + \Delta E_{Str} + \Delta E_{int} \quad (2)$$

$$\Delta E_{act} = \sum_i \frac{E^T{}_i - E^0{}_i}{\ln E^T{}_i - E^0{}_i} \ln\left(\frac{Q^T}{Q^0}\right) \quad (3)$$

$$\Delta E_{Str} = \sum_i \frac{E^T{}_i - E^0{}_i}{\ln E^T{}_i - E^0{}_i} \ln\left(\frac{S^T{}_i}{S^0{}_i}\right) \quad (4)$$

$$\Delta E_{int} = \sum_i \frac{E^T{}_i - E^0{}_i}{\ln E^T{}_i - E^0{}_i} \ln\left(\frac{I^T{}_i}{I^0{}_i}\right) \qquad (5)$$

Where:

i: subsector
T: the last year of the period
T=0: the base year of the period
E: total energy consumption
ΔE_{tot}: aggregate change in total energy consumption

The subscripts "act," "str," and "int" denote the effects associated with the overall activity level, structure, and sectoral energy intensity, respectively.

$$Q = \sum_i Q_i \text{ : total activity level} \qquad (6)$$

$$S_i = \sum_i Q_i / Q \text{ : activity share of sector I} \qquad (7)$$

$$I_i = \sum_i E_i / Q_i \text{ : energy intensity of sector I} \qquad (8)$$

Within the Industry category, activity is the value added of each sector or subsector. After conducting the decomposition analysis for Industry as a whole, the authors developed several scenarios by excluding the most influential industrial subsector from the analysis in order to assess the effect of that industry subsector on the decomposition analysis results.

In decomposition analysis, energy intensity is often calculated based on economic output. This is because, in decomposition analysis, the energy intensity and output of different sectors are added together (see Equation 2-8); to make this addition possible, the same unit must be used for the output of all sectors. Moreover, data on physical output can prove challenging to gather.

3. California industry energy use and value added data

3.1. Energy use trends

In 2008, electricity consumption represented about 13% of total final energy use in the industry sector. The electricity use trends in California industry between 1997 and 2008 indicate that the top three electricity-consuming industry subsectors during this period were "Electric and electronic equipment manufacturing," "Oil refineries," and "Food product manufacturing." Although it fluctuated during the study period, the electricity use of the "Oil refineries" subsector was almost the same in 2008 as in 1997. In the "Electric and electronic equipment manufacturing" and "Food product manufacturing" subsectors, however, electricity use decreased by 25 percent and increased by 13 percent, respectively, from 1997 to 2008. Comparing 2008 to 1997 levels, we see the greatest change in absolute electricity use in "Miscellaneous manufacturing," with a 710 percent increase, followed by "Primary metal manufacturing," with a 62 percent decrease.

Between 1997 and 2008, "Oil refineries" and "Oil and gas extraction" were the top two fuel-consuming California industry subsectors. The absolute fuel use of the "Oil refineries" subsector was 7 percent higher in 2008 than in 1997, and the fuel use of the "Oil and gas extraction" subsector dropped by 15 percent from 1997 to 2008. "Apparel manufacturing" and "Wood products manufacturing" showed the greatest drop in absolute fuel use, by more than 85 percent from 1997 to 2008.

Table 2 shows the total final [2] energy use (sum of electricity and fuel use) in different California industry subsectors from 1997 to 2008. "Oil refineries," "Oil and gas extraction," and "Miscellaneous manufacturing" were the top three energy-consuming subsectors during this period. The "Apparel manufacturing," "Wood product manufacturing," and "Pulp and paper manufacturing/printing and publishing" subsectors showed the greatest percentage decrease in absolute final energy use from 1997 to 2008. The sum of final energy use of all industry subsectors dropped by 5 percent from 1997 to 2008.

Table 2: Total Final Energy Use of California Industry Subsectors in 1997 and 2008

No.	Subsector	1997	2008	Change in 2008 compared to 1997 level
1	Food product manufacturing	85,882	81,134	-6%
2	Textile and textile product mills	10,234	6,752	-33%
3	Apparel manufacturing	3,798	1,372	-64%
4	Wood product manufacturing	9,601	3,271	-66%
5	Furniture and related product manufacturing	2,005	1,688	-17%
6	Pulp and Paper manufacturing and Printing and Publishing	57,395	23,844	-58%
7	Chemical manufacturing	86,409	94,322	9%
8	Plastics and rubber products manufacturing	12,872	10,023	-22%
9	Nonmetallic mineral product manufacturing	82,294	64,780	-21%
10	Primary metal manufacturing	24,899	13,610	-45%
11	Fabricated metal product manufacturing	19,202	17,408	-10%
12	Machinery manufacturing	9,390	7,596	-20%
13	Electric and Electronic Equipment manufacturing	40,092	29,436	-27%
14	Transportation equipment manufacturing	20,679	12,766	-38%
15	Oil refineries	535,230	570,785	7%
16	Miscellaneous manufacturing	62,670	107,194	71%
17	Oil and Gas Extraction	427,720	370,641	-13%
	Total	1,490,372	1,416,729	-5%

(Unit: Terajoules)

"Oil refineries" was the dominant energy-consuming subsector, followed by "Oil and gas extraction." The other large energy-consuming sectors were "Food product manufacturing," "Chemical

[2] In final energy, electricity use is equal to electricity consumption at the end use.

manufacturing," and "Miscellaneous manufacturing." The "Oil refineries" subsector's share of total industry energy use increased by 4 percent from 1997 to 2008, and the "Oil and gas extraction" subsector's share dropped by 3 percent (Table 2).

3.2. Industry value-added trends

California has the largest population among U.S. states, and about 13 percent of the California workforce is in the manufacturing sector (USDOE/EERE, 2010). Industry accounted for 13 percent of California's total GDP (in chained year-2005 dollars [3]) in 2008 (BEA/UDC, 2010). Table 3 shows the value added of different California industry subsectors between 1997 and 2008 in millions of chained 2005 dollars (BEA/UDC, 2010). The authors chose to use chained 2005 dollars to present value-added data in real terms, subtract for fluctuations due to inflation, and better reflect variations.

The total value added (in chained 2005 dollars) of California industry in 2008 was 67 percent higher than in 1997. The greatest increase in value added was in the "Electric and electronic equipment manufacturing" subsector, with a 603-percent rise, and the "Oil refineries" subsector, with a 144-percent rise. "Electric and electronic equipment manufacturing" shows clear growth in Table 3, dominating the value-added share of California industry when value added is presented in chained 2005 dollars. The "Electric and electronic equipment manufacturing" subsector's share of total industry value added increased from 7 percent in 1997 to 30 percent in 2008.

[3] Unlike fixed-weight measures, chain-weighted measures are not based on the price weights of a single base year but on the prices and quantities of adjacent years. BEA/UDC (2006) indicates that chain-weighted, value-added values are not additive because they are based upon geometric means. This means that total real value added of industry might be different from the value obtained by summing the real chained value added of each industry subsector. In our analysis of California industry, this difference is very small (zero to one percent) from 2000 to 2008, but it is larger for the years 1997 to 2009.

Table 3: Real Value Added of Different California Industry Subsectors in 1997 and 2008 (BEA/UDC, 2010)

No.	Subsector	1997	2008	Change in 2008 compared to 1997 level
1	Food product manufacturing	15,310	19,798	29%
2	Textile and textile product mills	1,257	1,015	-19%
3	Apparel manufacturing	3,649	4,079	12%
4	Wood product manufacturing	2,441	2,288	-6%
5	Furniture and related product manufacturing	3,227	2,867	-11%
6	Pulp and Paper manufacturing and Printing and Publishing	6,989	5,806	-17%
7	Chemical manufacturing	9,532	16,864	77%
8	Plastics and rubber products manufacturing	4,233	4,492	6%
9	Nonmetallic mineral product manufacturing	3,626	3,159	-13%
10	Primary metal manufacturing	2,534	1,413	-44%
11	Fabricated metal product manufacturing	11,588	11,268	-3%
12	Machinery manufacturing	8,104	8,902	10%
13	Electric and Electronic Equipment manufacturing	10,224	71,892	603%
14	Transportation equipment manufacturing	12,271	15,429	26%
15	Oil refineries	18,068	44,054	144%
16	Miscellaneous manufacturing	7,184	12,658	76%
17	Oil and Gas Extraction	22,029	11,034	-50%

(Unit: millions of chained 2005 dollars)

However, when industry value added is presented in current dollars (instead of chained 2005 dollars), the "Electric and electronic equipment manufacturing" subsector's share of total industry value added actually decreased from 32 percent in 1997 to 24 percent in 2008. Figure 1 also shows how the growth rate of value added varies when it is presented in chained 2005 dollars versus current dollars.[4] This figure shows the significant change in monetary value of this sector's output and emphasizes the importance of correcting for monetary variation.

[4] It should also be noted that "hedonic price indexes" are used to calculate value added in chained year-2005 dollars. Hedonic price indexes are statistical tools for developing standardized per-unit prices for goods, such as computers, whose quality and characteristics change rapidly (Landefeld and Bruce, 2000). Use of hedonic price indexes may have a slight impact on the increased share of value added attributable to the "Electric and electronics equipment manufacturing" sector. However, Landefeld and Bruce (2000) argue that only a small share of the increase in measured growth in industry is associated with the use of hedonic price indexes.

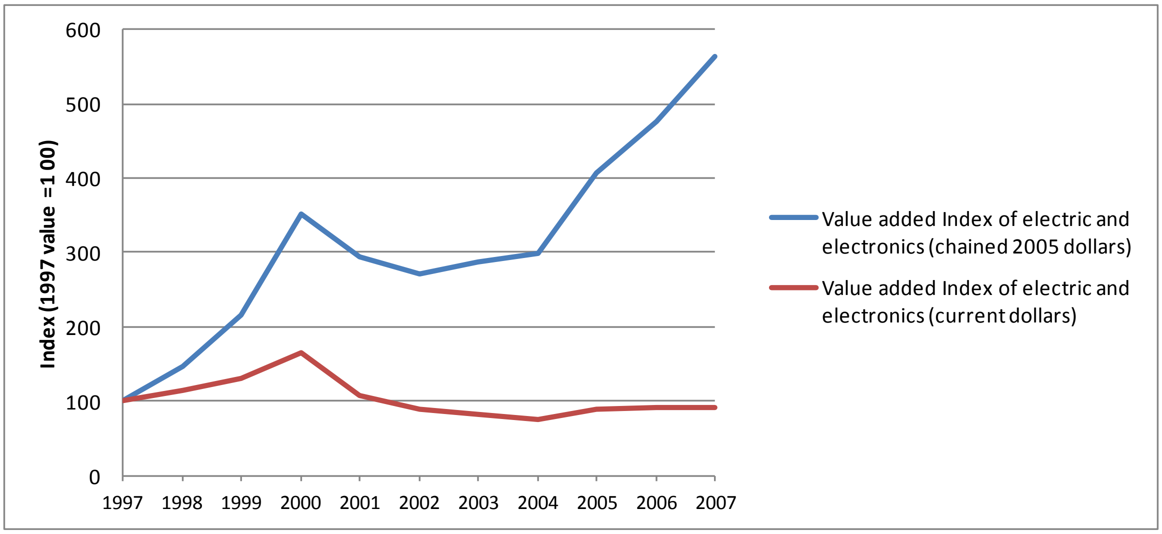


Figure 1: Value Added Index of "Electric and Electronic Equipment Manufacturing" in Current Dollars and Chained 2005 Dollars

Other subsectors that have experienced significant changes are "Chemical manufacturing" and "Food product manufacturing," whose value added increased by 77 percent and 29 percent respectively, and "Oil and Gas Extraction" and "Primary metal manufacturing," whose value added decreased by 50 percent and 44 percent, respectively.

4. Results and discussion

4.1. Energy intensity of California industry

Energy intensity based on economic output

Final energy use was divided by the value added of each subsector to determine the total final energy intensity for each subsector. Table 4 shows that "Oil and gas extraction" had the highest final energy intensity in terms of energy use per dollar of output in 2008, followed by "Nonmetallic minerals" and "Oil refineries." The lowest final energy intensity in 2008 was for "Apparel manufacturing," and the second-lowest was for "Electric and electronic equipment manufacturing." "Oil and gas extraction" was the only subsector whose final energy intensity was higher in 2008 than in 1997. "Electric and electronic equipment manufacturing" and "Apparel manufacturing" showed the greatest drop in final energy intensity from 1997 to 2008.

The actual final energy use of California industry did not change much (5 percent) from 1997 to 2008 (Figure 2). However, the overall value added increased significantly (67 percent) with the exception of a short period of decrease in 2001 and 2002 due to a recession and the collapse of many information technology companies. These trends resulted in a substantial decrease in overall industry energy intensity (43 percent). The next question is to determine what effects shaped this decrease; is it the result of reduced energy intensity of industries or of increasing shares of low-energy-intensive industries? The decomposition analysis described in the following sections helps to answer this question.

Table 4: Total Final Energy Intensity of Different California Industry Subsectors in 1997 and 2008

No.	Subsector	1997	2008	Change in 2008 compared to 1997
1	Food product manufacturing	5.6	4.1	-27%
2	Textile and textile product mills	8.1	6.6	-17%
3	Apparel manufacturing	1.1	0.3	-68%
4	Wood product manufacturing	3.9	1.5	-63%
5	Furniture and related product manufacturing	0.6	0.5	-7%
6	Pulp and Paper manufacturing and Printing and Publishing	8.2	4.1	-50%
7	Chemical manufacturing	9.1	5.6	-38%
8	Plastics and rubber products manufacturing	3.1	2.2	-27%
9	Nonmetallic mineral product manufacturing	22.7	20.5	-10%
10	Primary metal manufacturing	9.8	9.7	-2%
11	Fabricated metal product manufacturing	1.7	1.6	-7%
12	Machinery manufacturing	1.2	0.8	-27%
13	Electric and Electronic Equipment manufacturing	3.9	0.4	-90%
14	Transportation equipment manufacturing	1.7	0.8	-51%
15	Oil refineries	29.6	13.0	-56%
16	Miscellaneous manufacturing	8.8	8.4	-3%
17	Oil and Gas Extraction	19.4	33.6	73%

(Unit: GJ/billions of chained 2005 dollars)

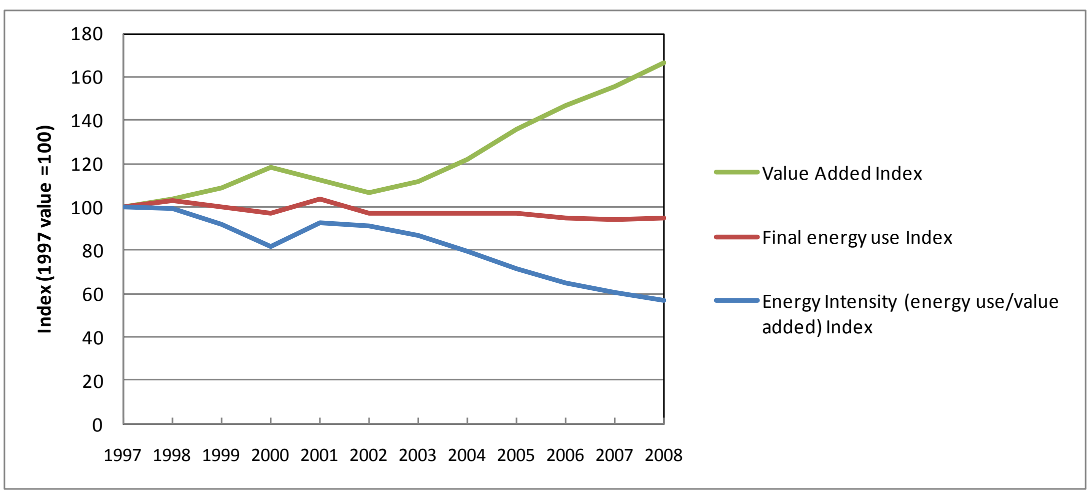


Figure 2: Trends in California Industry Value Added, Final Energy Use, and Final Energy Intensity Indexes (1997 intensity = 100) in 1997 and 2008

Energy intensity based on physical output

Energy intensity indicators based on physical activity are often preferred because they are not affected by any monetary fluctuations and have a closer relationship with technical (process) energy efficiency than do indicators based on economic output. However, gathering output data measured in physical units is often challenging; these data are not readily available for subsectors, especially at the state level in the U.S. Moreover, some subsectors produce a wide range of heterogeneous products that cannot be added together without losing valuable information related to different production process techniques and their energy requirements. For example in the "Food" subsector where the output is heterogeneous, measuring energy intensity in tonnes of food produced does not reflect the drivers of energy consumption, unless the detailed data at the firm-level is available (Ramírez et al. 2006). In some other industries, such as textile the quality and type of output produced is an important driver of energy use that is not reflected in the physical accounting of total output of the subsector. In these cases, only physical indicators at a more disaggregated level are sufficient to parameterize energy intensity.

Nevertheless, this study calculates the energy intensity for the "Cement" industry (the major energy consumer within the "Nonmetallic minerals" subsector), Oil refineries," and "Oil and gas extraction," which are the top three energy-consuming subsectors/activities within California industry. The authors chose these three sectors because energy intensity based on their physical output is a good indicator of changes in energy efficiency. In addition, reliable physical output data were only available for these three sectors.

Energy intensity of the California "Cement" industry

California produces more cement than any other state in the U.S., accounting for between 10 percent and 15 percent of U.S. cement production and cement industry employment (Coito et al., 2005b). In 2008, 11 cement plants existed in California, comprising 14 cement kilns and employing 1,700 people. Nine of these plants had preheater/precalciner rotary dry kilns. About 75 percent of grinding capacity used ball mills; the rest used roller mills. All plants were equipped with computer control systems.

Table 5 shows the energy use in the California cement industry and clinker and cement production from 1997 to 2008 in thousand metric tonnes (kt), based on data collected by USGS (USGS, 2010). Figure 3 shows the energy intensities of the California cement industry during the same period, based on the data in Table 5.

Table 5: Energy Use in the California Cement Industry and Clinker and Cement Production during 1997 - 2008

	Unit	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Fuel	TJ	40,800	38,731	45,466	45,532	43,313	45,676	46,149	46,704	46,884	44,024	45,334	36,547
Electricity	MWh	1,541,572	1,576,200	1,612,872	1,650,637	1,587,486	1,730,140	1,723,504	1,764,650	1,732,861	1,607,490	1,663,222	1,418,638
Clinker production	kt	9,824	9,965	10,645	10,617	10,148	11,186	11,283	11,593	11,466	10,648	10,879	9,574
Cement production	kt	10,430	10,427	10,756	11,362	10,634	11,733	12,184	12,614	12,259	11,073	11,355	10,216
Clinker : cement ratio		94%	96%	99%	93%	95%	95%	93%	92%	94%	96%	96%	94%

MWh:Megawatt hour

m^3: cubic meter

Source: USGC, 2010

When measured in physical units, the final energy intensity of the cement industry decreased by 8 percent from 1997 to 2008. On average, fuel intensity accounted for around 88 percent of total final energy intensity during this period. Based on world best practice energy intensity values (Worrell et al., 2008), there is room for energy-efficiency improvement in the California cement industry. However, comprehensive benchmarking of the energy intensity of this industry requires detailed data and information that are beyond the scope of this analysis. The information presented above on the technologies used in the California cement industry (CARB, 2008) shows the potential for improvement. For instance, the two cement plants that do not have preheater/precalciner rotary dry kilns could upgrade to this energy-efficient type of kiln. Replacing ball mills with vertical roller mills or a high-pressure roller press could also save significant electricity.

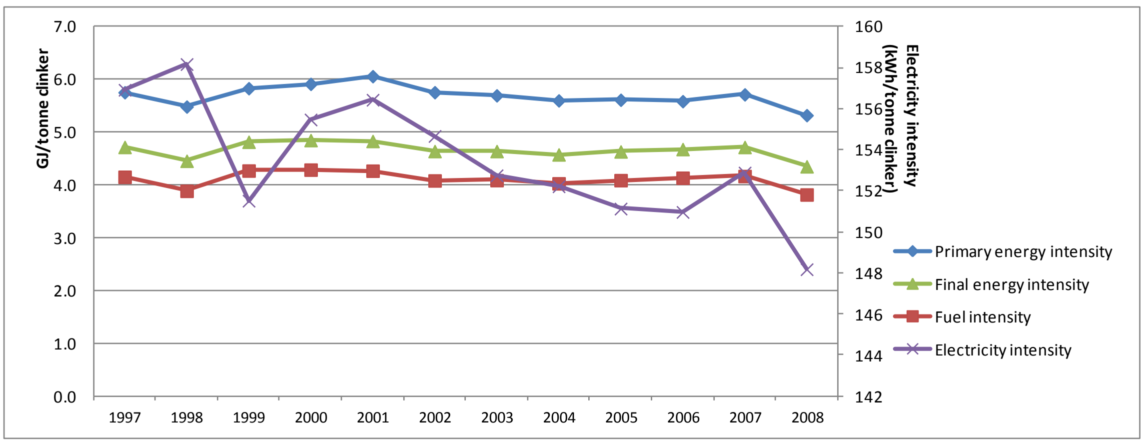


Figure 3: Energy Intensities of the California Cement Industry, 1997-2008

Note 1: Energy intensities are calculated per tonne of clinker, but total energy use in cement production, including finish grinding, is used in calculating energy intensities.
Note 2: In final energy, electricity use is equal to the electricity consumption at the end use. In primary energy, electricity use at the end use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) of all plants (including on-site generation) and transmission and distribution losses in each year. Description of data and methodology are available in the California Energy Balance Report (de la Rue du Can et al., 2011).

Energy intensity of the California "Oil refineries" industry

The "Oil refineries" subsector is the largest energy-using industry in California and the most energy-intensive industry in the U.S. After Texas and Louisiana, California has the largest oil refinery industry in the country. In 2004, 14 refineries operated by eight companies produced all the refined oil products in California (Worrell and Galitsky, 2004). Table 6 shows the energy use and production of the California "Oil refineries" subsector from 1997 to 2008. It should be noted that the fuel use does not include the feedstock. Figure 4 shows the calculated electricity and fuel intensities of this subsector. Because this subsector's electricity intensity is relatively low, the final and primary energy intensities are equal, with the addition of one decimal point, to fuel intensity; thus, they are not shown in the graph. Between

1997 and 2008, the electricity intensity varied between 7.9 kWh/ kilo (thousand) barrel (kbbl) and 10.2 kWh/kbbl, and the fuel intensity varied between 661.5 GJ/ kbbl and 751.2 GJ/kbbl.

Table 6: Energy Use and Production of the California Oil Refineries Subsector in 1997 and 2008

	unit	1997	2008
Electricity use	GWh	7,292	7,554
Fuel use	TJ	508,959	543,565
Production of petroleum products	kbbl	745,948	759,343

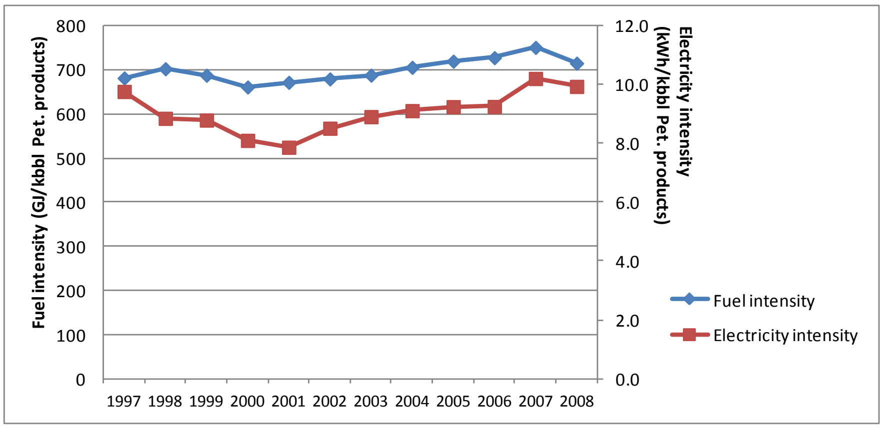


Figure 4: Electricity and Fuel Intensities of the California Oil Refineries Subsector, 1997-2008

Note: Because the electricity intensity of this subsector is relatively low, the final and primary energy intensities are equal to fuel intensity with the addition of one decimal point.

In this subsector, final energy intensity trends show different results depending on whether value added (economic) data or physical data are used. When value added data are used, the subsector showed a significant (56-percent) decrease in energy intensity from 1997 to 2008 (Table 4). When physical output data are used, the final energy intensity actually increased, from 682.6 GJ/kbbl in 1997 to 716.4 GJ/kbbl in 2008. Historical trend in the last two decades shows a move away from heavy fuels and towards lighter products such as gasoline and jet fuel in California. This increased demand for lighter products has resulted in increased conversion capacity at the refineries. Increased fuel quality required by regulation has resulted in a change in the quality of the gasoline produced in California. Both developments result in increased processing energy needs at the refineries (Worrell and Galitsky 2004). Energy consumption per unit of output can be a misleading indicator of the energy performance of refineries because it does not account for differences in complexities, output slates, or the type of crude processed.

Energy intensity of the "oil and gas extraction" industry

California produces slightly less than half of its crude oil and imports the rest. Table 7 shows the total production of crude oil in California and the electricity and fuel use in this subsector from 1997 to 2008.

Although this subsector produces crude oil and gas and some byproducts, the calculation of energy intensities uses only the crude oil production amount (see Figure 5). Because the electricity intensity of this subsector is low, the final and primary energy intensities are almost equal to fuel intensity with no decimal point added; thus, they are not presented in the graph. Between 1997 and 2008, the electricity intensity of this subsector varied between 12.3 kWh/kbbl and 20.7 kWh/kbbl, and the fuel intensity varied in the range of 1144.7 GJ/kbbl to 1450.7 GJ/kbbl of crude oil. Both electricity and fuel intensities showed overall increasing trends during this period, with a total final energy intensity increase of 16% between 1997 and 2008. When value added data were used in the analysis, the final energy intensity increased even more, by 73 percent in the same period (Table 4).

Table 7: California Oil and Gas Extraction Subsector Energy Use and Production in 1997 and 2008

	Unit	1997	2008
Electricity use	GWh	4,418	5170
Fuel use	TJ	411,788	352,072
Production of crude oil in California	kbbl	340,362	249,993

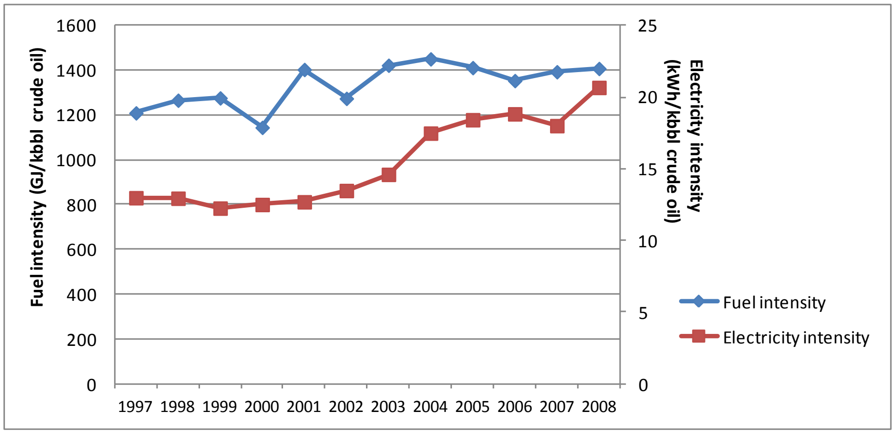


Figure 5: Electricity and Fuel Intensities of the California Oil and Gas Extraction Subsector, 1997-2008

Note: Because the electricity intensity of this subsector is low, the final and primary energy intensities are equal to fuel intensity with no decimal point added.

The increasing trend in "Oil and gas extraction" subsector energy intensity is mainly because oil extraction is becoming more and more difficult as oil wells are depleted. Therefore, energy-intensive technologies/processes such as enhanced oil recovery are used, which consume more energy per barrel of oil extracted.

As noted earlier, physical-activity energy intensity indicators are often preferred because they do not include monetary fluctuations and relate more closely to technical (process) energy efficiency than do economic indicators (Phylipsen et al 1998; Worrell et al., 1997). In addition, use of physical indicators improves comparability among different countries or states. A tonne of steel produced in one country is closer to a tonne of steel produced in another country than are the market values ($) of a tonne of steel in the two countries. However, in some cases, where the quality of output varies over time, physical energy intensity can be a misleading indicator of the energy-efficiency performance of an industry, as seen in the case of "Oil refineries". In that case, only physical indicators at a more disaggregated level are sufficient to parameterize energy intensity. However, this type of information proves very challenging to collect.

Therefore, energy intensity based on value added might prove to be a better indicator of energy-efficiency performance at the subsector level for some industries. For instance, this study shows that the energy intensity of the "Oil refineries" subsector decreased between 1997 and 2008 when calculated based on value added data but increased during the same period when calculated based on physical output (barrels of petroleum products). However, the output product is not exactly the same over the years because its quality improved. The better-quality products cost more, resulting in an increase in value added. When the energy intensity is calculated based on economic output, the increased value of the products is taken into account, resulting in a decrease in final energy intensity during the study period.

On the other hand, when the intensity is calculated based on physical output, this increased product quality is not taken into account, resulting in an increase in energy intensity. However, more information is needed to understand how price indexes that correct for inflation are estimated. In the analysis of the energy intensity trends of different industrial subsectors, special attention should be paid to each industry's technology, to changes in the product portfolio over time, and to the drivers for such changes (e.g., environmental regulations as mentioned above). Furthermore, using the value added as the economic output may not capture the intra-sectoral changes in structure. For example, in Californian food industry, tomatoes processing is an important sector, while value added may have been increased mostly due to the increasing role of the wine industry. In electric and electronics product manufacturing sector, chip manufacture (e.g. clean rooms) are the key energy user. Understanding of the industry context will help in interpreting analysis results.

4.2. Decomposition of California industry energy use

The authors performed LMDI decomposition analysis for California industry for three time periods: 1997-2000, 2000-2004, and 2004-2008. These three periods were chosen based on the final California energy intensity trends from 1997 to 2008. The authors also carried out decomposition analysis for the entire period, 1997-2008, to show the overall change in energy use. As mentioned in the Methodology section, additive decomposition analysis was used as well as the changing analysis method, in which the base year moves from year to year. Figure 6 shows the results of the additive decomposition analysis of total final energy use for all of California industry for the time periods mentioned above.

Figure 6 illustrates that, from 1997 to 2000, activity and structural effects were the two dominant – and opposite – influences. The activity effect increased final energy use by 252 Petajoule (PJ), but the structural effect reduced it by 403 PJ during the same period. Once the intensity effect (105 PJ) is taken into account, overall final energy use by industry declined by 45 PJ. However, during the next period, 2000-2004, the two major effects were structural and intensity effects. Unlike in the previous period, the intensity effect during the period 2000-2004 reduced final energy use by 95 PJ, while the structural effect increased it by 62 PJ. Thus, the overall change in final energy use by California industry during this period was a 5 PJ increase, which is a small change. The last period, 2004-2008, had a very large positive activity effect (+444 PJ), a large negative intensity effect (-461 PJ), and a minor structural effect (-17 PJ). Overall final energy use in this period decreased by 34 PJ.

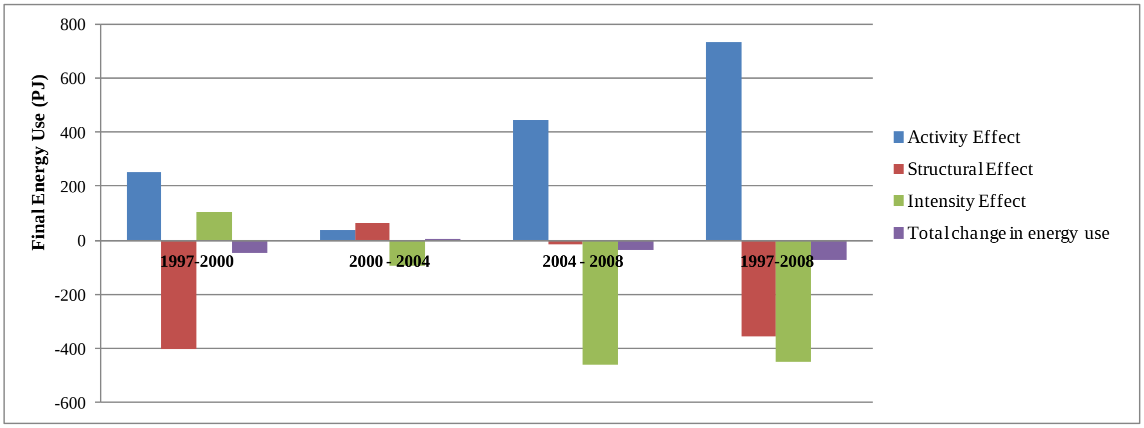


Figure 6: Results of Additive Decomposition (Changing Analysis) of Final California Industry Energy Use in Different Periods

Over the whole period, 1997-2008, both the structural and intensity effects pushed final energy use downward while the activity effect was positive, increasing final industry energy use. The sum of these three effects was a decline in final energy use by 74 PJ in 2008 compared to 1997. Overall, the reduction in final industry energy intensity was due to both reduction in energy intensity of subsectors and an increase in less-energy-intensive subsectors. Figure 6 shows that the intensity effect was slightly larger than the structural effect, the structural effect took place mostly during the first period (1997 to 2000), and the intensity effect took place mostly during the last period (2004 to 2008).

The negative intensity effect that started during the second analysis period, 2000 to 2004, and amplified during the last period, 2004 to 2008, could likely be the result of an escalation in energy prices, among other possible drivers. Starting in 2000 and continuing until 2008, the price of natural gas supplied to California industry more than doubled (2.3 times) (Figure 7). Similarly, the price of electricity increased by around 50 percent. The energy price upsurge experienced by California industries during this period pressured them to improve energy efficiency to reduce energy costs. Also, the increased energy prices in energy-intensive industry leads to a lower value added, thereby tend to increase the energy intensity calculated per value added. Thus, plants need to improve their energy efficiency to deal with the increasing energy price. Moreover, California specified very aggressive electricity and natural gas energy-efficiency targets for its investor-owned utilities in 2006. To meet these targets, energy-efficiency programs that traditionally targeted residential and commercial customers were expanded to address energy-savings opportunities for industrial customers. There might be a few other reasons why the energy intensity effect is negative during this period which could be the subject of further investigations.

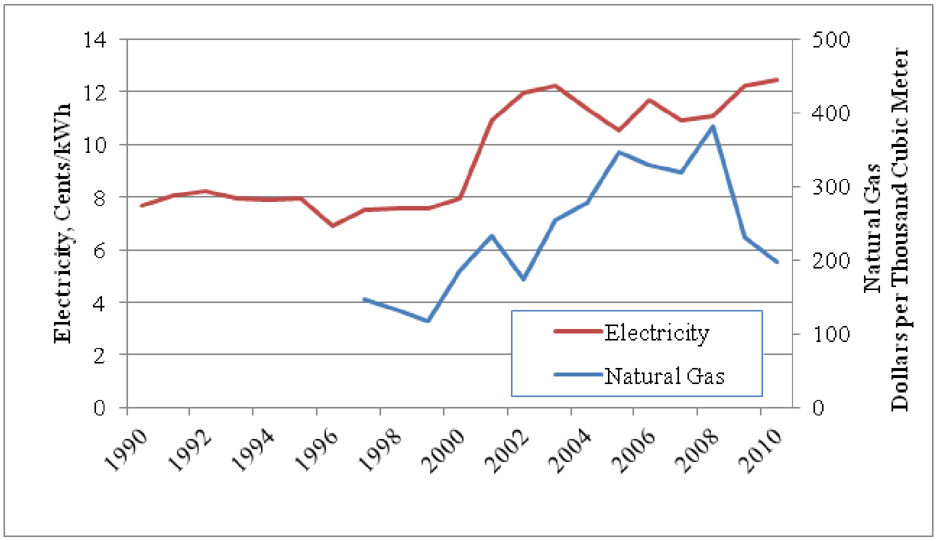


Figure 7: Energy Prices for California Industry, 1990-2010

Sources: EIA (2011) and CEC (2011)

The activity effect in all periods is positive because the real value added in chained 2005 dollars increased during these periods (Figure 6). However, the real value added dropped in 2001 - 2003 compared to that in 2000. This was mostly a result of the recession that started in 2000 in both California and the U.S. Figure 8 presents the results of the additive decomposition (changing) analysis in annual format, and Figure 9 presents the results by industry subsectors.

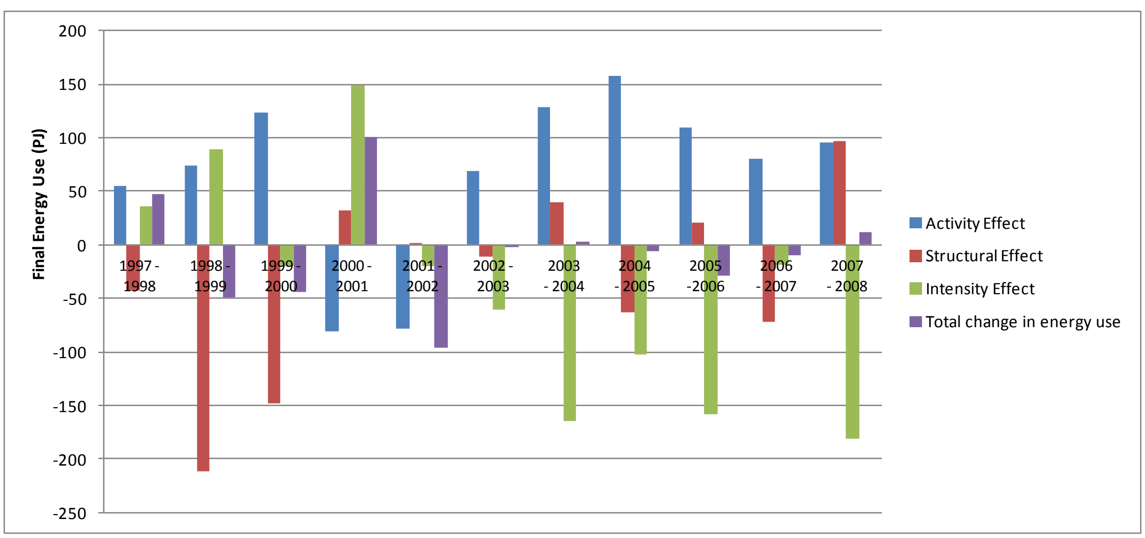
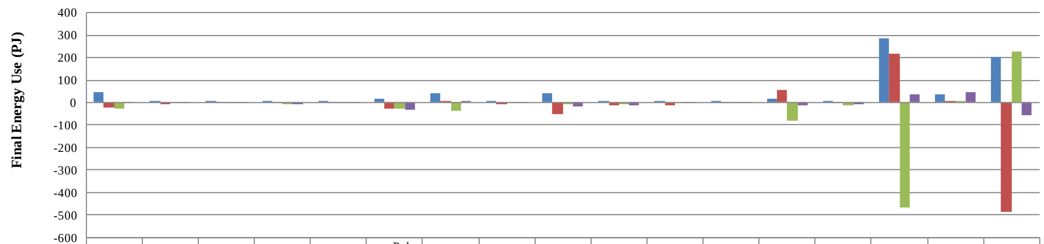


Figure 8: Annual Results of Additive Decomposition (Changing Analysis) of Final California Industry Energy Use



	Food product manufacturing	Textile and textile product mills	Apparel manufacturing	Wood product manufacturing	Furniture and related product manufacturing	Pulp and Paper manufacturing and Printing and Publishing	Chemical manufacturing	Plastics and rubber products manufacturing	Nonmetallic mineral product manufacturing	Primary metal manufacturing	Fabricated metal product manufacturing	Machinery manufacturing	Electric and Electronic Equipment manufacturing	Transportation equipment manufacturing	Petroleum manufacturing	Miscellaneous manufacturing	Oil and Gas Extraction
Activity Effect	45	5	1	3	1	18	44	6	41	8	10	4	17	7	288	35	202
Structural Effect	-21	-6	-1	-3	-1	-25	2	-6	-51	-13	-10	-3	55	-4	216	1	-487
Intensity Effect	-29	-2	-3	-6	0	-26	-38	-3	-7	-6	-1	-3	-82	-11	-469	8	228
Total change in energy use	-5	-3	-2	-6	0	-34	8	-3	-18	-11	-2	-2	-11	-8	36	44	-57

Figure 9: Results of Additive Decomposition of Final Energy Use by Different California Industry Subsectors, 1997-2008

The structural effect during 1997 to 2008 is also large. The major contributor to the structural effect was the decrease in the "Oil and gas extraction" subsector's share of total industry value added and the increase in the "Electric and electronic equipment manufacturing" subsector's share. The "Oil and gas extraction" subsector is very energy intensive, and its value added share decreased from 15 percent in 1997 to 5 percent in 2008 because of a significant reduction in production. At the same time, the non-energy-intensive "Electric and electronic equipment manufacturing" subsector's share of total industry value added increased significantly from 7 percent in 1997 to 30 percent in 2008 (see Table 3). This subsector's share of total final energy use represented only 2 percent in 2008 (see Table 2). This significant increase in the value-added share of "Electric and electronic equipment manufacturing" also meant that the share of value added from other energy-consuming sectors such as "Nonmetallic minerals" decreased, from 3 percent in 1997 to 1 percent in 2008. "Oil refineries," "Nonmetallic minerals," and "Oil and gas extraction" are highly energy-intensive industries with final energy intensities of 13.0 GJ/billion of chained 2005 dollars, 20.5 GJ /billion of chained 2005 dollars, and 33.6 GJ/billion of chained 2005 dollars in 2008, respectively. These intensities are much greater than those of other industry subsectors. Therefore, even a small change in the share of value added of these three subsectors will have a significant impact on structural effect.

Figure 6 shows a positive intensity effect during the period 1997-2000, which pushed final energy use upward. This is again mainly because of the top energy-consuming subsector, "Oil and gas extraction." As mentioned, the energy intensity of this subsector is much higher than that of other subsectors (Table 4). The final energy intensity of this subsector showed an increasing trend from 1997 to 2000 (Table 4). In the other two analysis periods as well as during the whole period from 1997 to 2008, the intensity effect is negative.

The annual decomposition results in Figure 8 also show that the activity effect increased final industry energy use in all annual periods over the time frame of this study except in 2000-2001 and 2001-2002 when there was a decreasing trend in the real value added of the industry. The structural effect decreased the industry final energy use in most annual periods within the study time frame.

In 2000-2002, while the real value added of "Electric and electronic equipment manufacturing" declined, its share of the total manufacturing sector value added declined slightly as well. At the same time, the share of real value added for the top two energy-intensive sectors – "Oil and gas extraction" and "Nonmetallic minerals" – increased, which resulted in a positive structural effect for the period. The significant jump in intensity effect in 2000-2001 is because of the sudden drop in real industry value added at the start of the recession. Final industry energy use increased during this period, which resulted in a significant increase in final energy intensity.

Breaking down the decomposition analysis results by industrial subsectors shows the contribution of each subsector to the overall results (Figure 9). In all industrial subsectors, the activity effect on final energy use was positive during the period analyzed. However, the structural effect of all industries was negative except for "Oil refineries," "Electric and electronic equipment manufacturing," and "Chemical manufacturing." This implies that the share of these three industries in the total industry value added increased from 1997 to 2008, and the share of all other industries decreased. Only "Oil and gas extraction" and "Miscellaneous manufacturing" had positive intensity effects. This confirms that only the final energy intensity of "Oil and gas extraction" increased in the year 2008 compared to energy intensities in 1997.

The final energy intensity of "Miscellaneous manufacturing" increased sharply until the year 2001 and then showed a decreasing trend until the year 2008 when it ended slightly lower than in 1997. The overall effect of this trend is a very small positive intensity effect. The "Oil refineries" and "Oil and gas extraction" sectors are the two sectors that have major influence on the change in overall industry energy use during this period because both are highly energy intensive, so changes in the share of their value added and in their final energy intensity will result in large structural and intensity effects, respectively. In the case of California industry, the structural and intensity effects of these two sectors act in opposition to each other (Figure 9).

4.3. Scenario analysis

As stated above, three sectors are the major contributors to the decomposition analysis results: "Electric and electronic equipment manufacturing," "Oil refineries," and "Oil and gas extraction." "Electric and electronic equipment manufacturing" accounted for a large share of value added although it used a small share of industry final energy. "Oil and gas extraction"[5] had the highest final energy intensity in 2008 and was the only subsector whose energy intensity increased from 1997 to 2008. To further assess the influence of these two sectors on the decomposition analysis results, the authors performed decomposition analysis of scenarios that each excluded one of these sectors. The results of the scenario analyses are presented below.

[5] This subsector is often classified in the energy transformation sector and not in manufacturing.

Scenario 1: Decomposition analysis excluding the "Electric and electronic equipment manufacturing" sector

Figure 10 shows the results of additive decomposition analysis of final California industry energy use from 1997 to 2008, excluding the "Electric and electronic equipment manufacturing" subsector. As in the base-case analysis (Figure 6), the activity effect is positive, and the structural effect, intensity effect, and total change in energy use are negative. However, because the "Electric and electronic equipment manufacturing" subsector, which accounts for a significant share of total industry value added, is excluded in this scenario, the activity effect is smaller in this scenario than in the base case. Similarly, the structural effect value in Scenario 1 is lower than that of the base case and is very small. This is because, in the base-case analysis, the "Electric and electronic equipment manufacturing" subsector's share of value added increased substantially over the study period and dominated the industry value added, pushing down "Oil and gas extraction" subsector's share of value added. In this scenario, the structural effect of "Oil refineries" increases, and the structural effect of "Oil and gas extraction" decreases. Because these two offset each other, the structural effect is almost null. The intensity effect of this scenario is also largely influenced by the "Oil and gas extraction" and "Oil refineries" subsectors. However, the decrease in energy intensity of "Oil refineries" dominates, which results in a negative intensity effect.

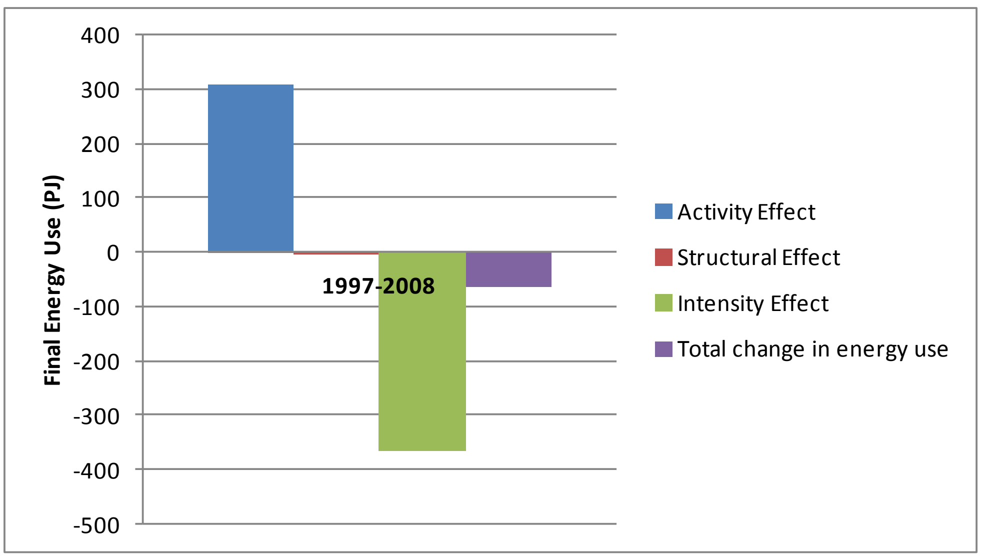


Figure 10: Results of Additive Decomposition (Changing Analysis) of Final California Industry Energy Use, 1997-2008, Excluding the Electric and Electronic Equipment Manufacturing Subsector

Scenario 2: Decomposition analysis excluding the "Oil and gas extraction" subsector

Figure 11 shows the results of additive decomposition analysis of California industry final energy use from 1997 to 2008 with the "Oil and gas extraction" subsector excluded. As expected, the activity effect is still positive because of the increase in value added during this period. The structural effect is almost zero in this scenario. Without the "Oil and gas extraction" subsector, the structural effect is driven mostly by the increasing share of value added in the "Electric and electronic equipment manufacturing" subsector, which has a negative effect, and the "Oil refineries" subsector, which has a positive effect on energy demand. In this scenario, the structural effect of the "Oil refineries" subsector increases while the structural effect of "Electric and electronic equipment manufacturing" decreases. These two offset each other, so the structural effect is almost null.

In this scenario, the intensity effect is much larger because the final energy intensity of the "Oil and gas extraction" subsector, which increases, is excluded. The final energy intensity of all subsectors included in this scenario decreased in 2008 compared to 1997. Therefore, the resulting intensity effect is negative, leading to a small overall energy intensity (final energy use per value added) decrease for the period 1997 to 2008.

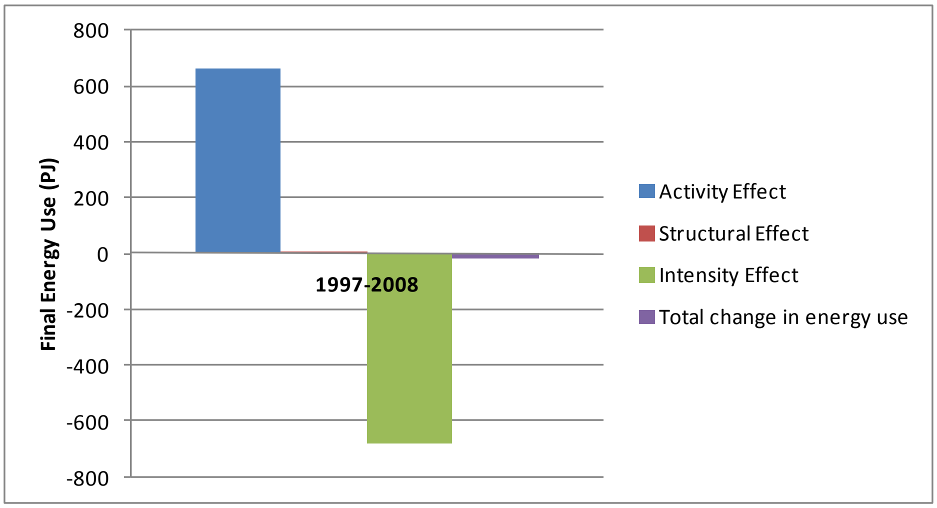


Figure 11: Results of Additive Decomposition (Changing Analysis) of California Industry Final Energy Use, 1997-2008, Excluding the Oil and Gas Extraction Subsector

5. Conclusions

The decomposition analysis described in this paper shows that energy intensity reduction was not the only reason for reduced energy demand in California industry between 1997 and 2008. Structural effects played an almost equivalent role in reducing energy demand, notably because of the major decrease of the "Oil and gas extraction" subsector's share of total industry value added and the increase of the "Electric and electronic manufacturing" subsector's share of total industry value added.

The analysis results show that energy-intensive subsectors such as "Oil refineries," "Non metallic minerals," and "Oil and gas extraction" use more energy per value added, and, although they account for a large share of California industry's final energy use (71 percent in 2008), they together produced only 25 percent of total industry value added in 2008. In contrast, the "Electric and electronic manufacturing" subsector accounted for 30 percent of the industry value added alone while just consuming 2 percent of the total final industry energy use in 2008. These four subsectors have a major influence on the results of the decomposition analysis.

The results of this decomposition analysis show that the intensity effect started pushing final California industry energy use downward in 2000. This timing corresponds to an energy price upsurge experienced by California industries at the same time, which has continued, pressuring industries to improve energy efficiency to reduce costs. Thus, the downward trend in final energy use that started in 2000 has since amplified.

More research is needed to determine the best indicators of energy use for each Industry subsector. Energy intensities expressed in terms of physical or monetary output can produce different results. For complex and heterogeneous industries, more disaggregate data may be required to develop meaningful indicators of energy efficiency.

There is no direct way of measuring energy savings. Hence, one must rely on a series of indicators to infer changes in energy efficiency. Many countries have developed indices of energy efficiency performance for monitoring purposes, and, increasingly, as a basis for policy making. Theses indices are based on energy intensity effects calculated at a disaggregated level but summarize results at more aggregate levels. The purpose of these indices is to provide a quick assessment tool for policy makers, that is based on meaningful analysis. This study's research on decomposition analysis can serve as the starting point in developing similar indices for California. Ultimately, this index could be used as a performance index to measure progress in overall energy efficiency in California.

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References

Ang, B.W., 2004. Decomposition analysis for policymaking in energy: which is the preferred method?, Energy Policy 32 (2004), pp. 1131–1139.

Ang, B.W. 2005. The LMDI approach to decomposition analysis: a practical guide. Energy Policy 33 (2005) 867–871.

Ang, 2006. Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index. Energy Policy (2006), Volume: 34, Issue: 5, Pages: 574-582

Ang B.W. and S.Y. Lee, Decomposition of industrial energy consumption: some methodological and application issues. Energy Economics 16 (1994), pp. 83–92.

Ang, B.W.; Mu, A.R.; Zhou, P. 2010. Accounting frameworks for tracking energy efficiency trends. Energy Economics, Volume 32, Issue 5, September 2010, Pages 1209-1219.

Asia Pacific Energy Research Centre (APERC), 2001.Energy Efficiency Indicators: a Study of Energy Efficiency Indicators in APEC Economies. March 2001.

Bhattacharyya, S.C. and Ussanarassamee, A. 2005. Changes in energy intensities of Thai industry between 1981 and 2000: a decomposition analysis. Energy Policy 33 (2005) 995–1002.

Bureau of Economic Analysis, U.S. Department of Commerce (BEA/UDC). 2010. Gross Domestic Product by State. Available at http://www.bea.gov/regional/gsp/.

California Air Resources Board (CARB). 2008. Overview: AB32 implementation status. Available at: http://www.arb.ca.gov/cc/cement/meetings/041008/041008presentations.pdf.

California Energy Commission (CEC). 2011. Statewide Average Customer Class Electricity Prices. Available at: energyalmanac.ca.gov/electricity/Electricity_Rates_Combined.xls

Coito, F.; Worrell, E.; Price, L.; Masanet, E.; Friedmann, R.; Rufo, M. 2005a. California Industrial Energy Efficiency Potential. Berkeley, CA: Lawrence Berkeley National Laboratory. Available at http://industrial-energy.lbl.gov/node/222.

Coito, F.; Powell, F.; Worrell, E.; Price, L.; Friedmann, R.; Rufo, M. 2005b. Case Study of the California Cement Industry. Berkeley, CA: Lawrence Berkeley National Laboratory. Available at http://ies.lbl.gov/iespubs/59938.pdf.

de la Rue du Can, S., J. Sathaye, L. Price, and M. McNeil. 2010. Energy Efficiency Indicators Methodology Booklet. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-3702E. May.

de la Rue du Can, S.; Hasanbeigi, A.; Sathaye, J. 2011. California Energy Balance Update and Decomposition Analysis for the Industry and Building Sectors. Berkeley, CA: Lawrence Berkeley National Laboratory. Report prepared for the California Energy Commission.

Farla, J.C.M.; Blok, K., 2000. The use of physical indicators for the monitoring of energy intensity developments in the Netherlands, 1980–1995. Energy 25, 609–638.

International Energy Agency (IEA). 2004. Oil Crises & Climate Challenges- 30 Years of Energy Use in IEA Countries. Available at http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1260.

Jollands, N. J.; Lermit, and Patterson M. 2004, Aggregate eco-efficiency indices for New Zealand- a principal components analysis. Journal of Environmental Management 73 (2004) 293–305.

Landefeld, J. S. and Bruce T. G. 2000. A Note on the Impact of Hedonics and Computers on Real GDP. Survey of current business 80 (December 2000): 17–22.

Liu, F.L.; Ang, B.W. 2003. Eight methods for decomposing the aggregate energy-intensity of industry. Applied Energy 76 (2003) 15–23.

Nanduri, M.; Nyboer, J.; Jaccard, M., 2002. Aggregating physical intensity indicators: results of applying the composite indicator approach to the Canadian industrial sector. Energy Policy 30, 151–163.

Patterson M. G., 1993. An accounting framework for decomposing the energy-to-GDP ratio into its structural components of change, Energy, Volume 18, Issue 7, July 1993, Pages 741-761.

Phylipsen, G. J. M., K. Blok and E. Worrell. 1998. Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry. Utrecht: Department of Science, Technology and Society, Utrecht University.

Ramírez, C.A.; Blok, K.; Neelis, M.; Patel, M., 2006. Adding apples and oranges: The monitoring of energy efficiency in the Dutch food industry. Energy Policy, Volume 34, Issue 14, September 2006, Pages 1720-1735

Reddy, B.S. and Ray, B.K. 2010. Decomposition of energy consumption and energy intensity in Indian manufacturing industries. Energy for Sustainable Development 14 (2010) 35–47.

Salta, S.; Polatidis, H.; Haralambopoulos, D. 2009. Energy use in the Greek manufacturing sector: A methodological framework based on physical indicators with aggregation and decomposition analysis. Energy 34 (2009) 90–111.

Schipper, L.; Meyers, S.; Howarth, R.B.; Steiner, R., (1992) Energy Efficiency and Human Activities: Past Trends, Future Prospects. Cambridge University Press, Cambridge, UK.

Schipper, L. 1997. Indicators of energy use and human activity: Linking energy use and human activity. Paris: International Energy Agency.

Schipper L., F. Unander, S. Murtishaw, and M. Ting. 2001. "Indicators of energy use and carbon emissions: explaining the energy economy link." Annual Review of Energy & the Environment 26: 49-81.

Taylor P., P. Cazzola, M. Francoeur, O. Lavagne d'Ortigue, M. Sturc, C. Tam and M. Taylor. 2007. "Energy Use in the New Millennium." Paris: International Energy Agency. http://www.iea.org/textbase/nppdf/free/2007/millennium.pdf

Unander, F. , M. Ting, L. Fulton, D. Justus, and S. Karbuz. 2004. Oil Crises and Climate Challenges: 30 Years of Energy Use in IEA Countries. Paris: International Energy Agency.

U.S. Bureau of Labor Statistics (US/BLS). 2010. Producer price Index-Industry data – discounted series. Available at http://data.bls.gov:8080/PDQ/outside.jsp?survey=nd

US Department of Energy/Energy Efficiency and Renewable Energy (US DOE/EERE). 2010. States activities and partnership – California. Available at http://apps1.eere.energy.gov/states/economic_indicators.cfm/state=CA

US Energy Information Administration (US EIA). 2010. State Energy Profile – California. Available at http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA

US Energy Information Administration (US EIA). 2011. Natural Gas Navigator . Available at http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htmU.S. Geological Survey (USGS). 2010. Fuel and Electricity Consumption by California Cement Plants, 1990-2008. Washington, DC: USGS.

Worrell, Ernst, Lynn Price, Nathan Martin, Jacco Farla and Roberto Schaeffer. 1997.Energy intensity in the iron and steel industry: a comparison of physical and economic indicators. Energy Policy, 25(7-9): 727-744.

Worrell, E.; Galitsky, C. 2004. Profile of the Petroleum Refining Industry in California. Berkeley, CA: Lawrence Berkeley National Laboratory. Available at http://ies.lbl.gov/iespubs/55450.pdf.

Worrell, E.; Price, L.; Neelis, M.; Galitsky, C.; Nan, Z. 2008. World Best Practice Energy

Intensity Values for Selected Industrial Sectors. Berkeley, CA: Lawrence Berkeley National Laboratory. Available at http://china.lbl.gov/publications/world-best-practice-energy-intensity-values-selected-industrial-sectors.